

**SENSOR DEVELOPMENT THERMOSPHERIC
NEUTRAL WIND MEASUREMENTS**

R. A. Heelis

**University of Texas at Dallas
William B. Hanson Center for Space Sciences
P. O. Box 830688, MS FO 22
Richardson, TX 75083-0688**

15 November 2003

Final Report

20040604 107

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED



**AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Rd
AIR FORCE MATERIEL COMMAND
Hanscom AFB, MA 01731-3010**

This technical report has been reviewed and is approved for publication.

// Signed//

BRONEK DICHTER
Contract Manager

// Signed //

ROBERT A. MORRIS
Branch Chief

This document has been reviewed by the ESC Public Affairs Office and has been approved for release to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center (DTIC). All others should apply to the NTIS.

If your address has changed, if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFRL/VSIM, 29 Randolph Rd., Hanscom AFB, MA 01731-3010. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

| REPORT DOCUMENTATION PAGE | | | Form Approved OMB No. 0704-0188 | | |
|--|-----------------------|-------------------------|---|---|--|
| Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS. | | | | | |
| 1. REPORT DATE (DD-MM-YYYY) 15-11-2003 | | 2. REPORT TYPE FINAL | | 3. DATES COVERED (From - To) 17 May 01 - 30 Sep 03 | |
| 4. TITLE AND SUBTITLE Sensor Development Thermospheric Neutral Wind Measurements | | | 5a. CONTRACT NUMBER F19628-00-C-0028 | | |
| | | | 5b. GRANT NUMBER | | |
| | | | 5c. PROGRAM ELEMENT NUMBER 61102F | | |
| 6. AUTHOR(S) R. A. Heelis | | | 5d. PROJECT NUMBER 2310 | | |
| | | | 5e. TASK NUMBER GD | | |
| | | | 5f. WORK UNIT NUMBER AM | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Texas at Dallas Center for Space Sciences P. O. Box 830668 MS/FO22 Richardson, TX 75083-0688 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER UTD-STR-A002-01-630117 | | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory 29 Randolph Road Hanscom AFB MA 01731-3010 | | | 10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/VSBXR | | |
| | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-VS-HA-TR-2004-1028 | | |
| 12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT This report summarizes activities related to the development of a sensor to measure the in-situ neutral wind from a satellite in low-earth orbit. This development work sponsored by the Air Force allowed a credible proposal for flight instrumentation to be submitted to NASA. That proposal was subsequently funded and paved the way for a collaborative investigation of ion-neutral coupling of scientific and technical value to both NASA and the Air Force. The project started a conceptual design for neutral wind sensors, the development of computer models of the instrument performance, evaluation of the instrument optics, design and construction of laboratory prototypes, and final construction of flight hardware. We briefly review the activities here making reference to previously released reports that provide more detail. | | | | | |
| 15. SUBJECT TERMS Thermosphere Neutral wind measurements Radio scintillation | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT SAR | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Bronek Dichter |
| a. REPORT UNCLAS | b. ABSTRACT UNCLAS | c. THIS PAGE UNCLAS | | | 19b. TELEPHONE NUMBER (include area code) 781-377-3991 |

CONTENTS

| | |
|------------------------------|----|
| List of Figures | iv |
| 1. INTRODUCTION | 1 |
| 2. INSTRUMENTATION | 2 |
| 2.1 Cross-Track Sensor | 2 |
| 2.2 Ram Wind Sensor | 4 |
| 3. CONCLUSIONS | 5 |

FIGURES

| | |
|--|---|
| 1. Geometrical Relationship Between Cross-Track and Ram Wind Components... | 1 |
| 2. Schematic Illustration of Arrival-Angle Measurement Scheme..... | 2 |
| 3. Computed Cross-Track Wind Sensor Performance..... | 3 |
| 4. Schematic Illustration of Ram Wind Sensor Configuration..... | 4 |
| 5. Ram Wind Sensor RPA Characteristics..... | 4 |

1. INTRODUCTION

The challenge we address relates to the specification of the dynamics of the thermosphere and its relationship to severe radio scintillation seen in space and on the ground. This specification must include a description of the neutral air wind velocity. In the upper atmosphere a satellite moves supersonically through the neutral gas and thus the spacecraft motion dominates the neutral gas velocity with respect to the sensor. Then three mutually perpendicular components of the neutral wind velocity can be measured using sensors designed to view the atmosphere approximately along the direction of motion of an orbiting satellite. Two sensors comprise the Neutral Wind Meter (NWM) that will provide a measure of the neutral wind velocity in the sensor reference frame. The ram wind sensor (RWS) will measure the neutral gas velocity along the sensor look direction called the ram wind component. The cross-track sensor (CTS) will measure the angle of arrival of the neutral gas in two mutually perpendicular planes with respect to the sensor look direction. A simple tangential relationship between these two parameters allows the cross-track wind components to be derived as shown in figure 1.

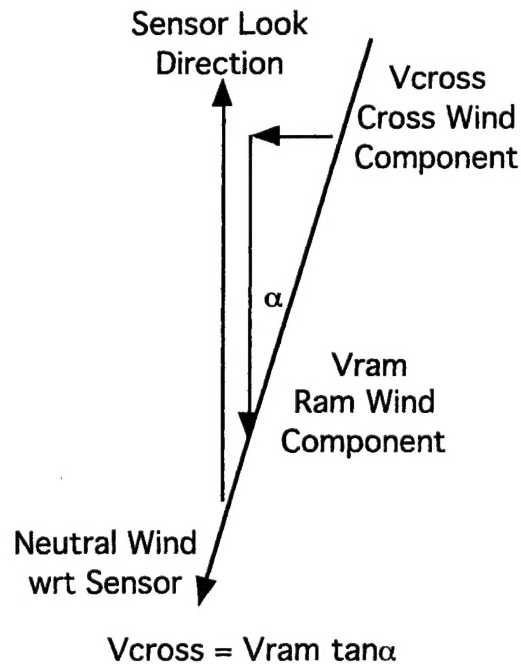


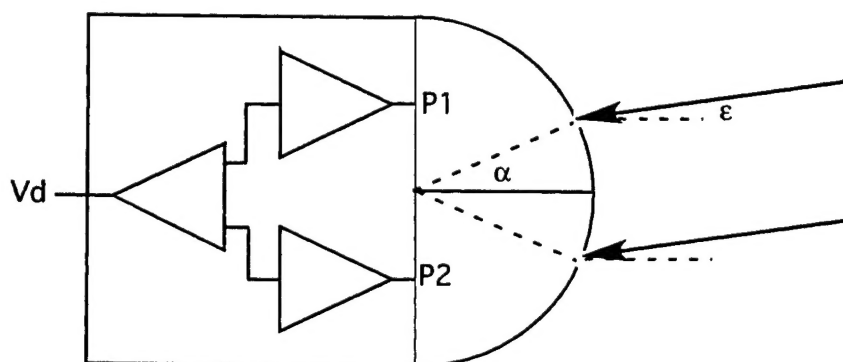
Figure 1. Geometrical Relationship Between Cross-Track and Ram Wind Components

2. INSTRUMENTATION

Two sensors that make up the NWM have been designed, constructed and extensively tested. A flight opportunity for these sensors will appear in November 2004 and at that time we expect to realize the first in-situ measurements of the neutral wind.

2.1 Cross-Track Sensor

The cross-track wind sensor is a differential pressure gauge that measures the neutral gas arrival angle by determining the ratio of the pressures in two adjacent pressure chambers that have small apertures making small angles with the ram direction. Figure 2 is a schematic illustration of the principles of operation making use of the simple relationship between the pressure ratio, obtained by taking the difference between outputs proportional to the logarithm of the pressure, and arrival angle of the gas.



$$V_d = G_d C \ln \left(\frac{P_1}{P_2} \right) = G_d C \ln \left(\frac{\cos(\alpha - \epsilon)}{\cos(\alpha + \epsilon)} \right)$$

Figure 2. Schematic Illustration of Arrival-Angle Measurement Scheme.

To simulate and verify the expected performance of this arrangement we must individually establish the behavior of the gauge and its associated logarithmic electrometer and of the difference amplifier used to determine the pressure ratio. It can be shown that the pressure in the chamber varies as the cosine of the angle of attack. Thus near zero angle the change in the pressure with angle is small. The challenge is therefore to provide an angle large enough to provide a meaningful angular variation but not so large that the pressure is too small to provide a good signal. We choose 22.5 degrees as the initial angular offset for this instrumentation. Figure 3 shows the output from an initial evaluation of the instrument performance. It shows that we may expect a pressure enhancement due to the spacecraft motion of about 20 and that even angles as small as 0.1 degrees can be measured if we can measure changes in the pressure of one part in one thousand.

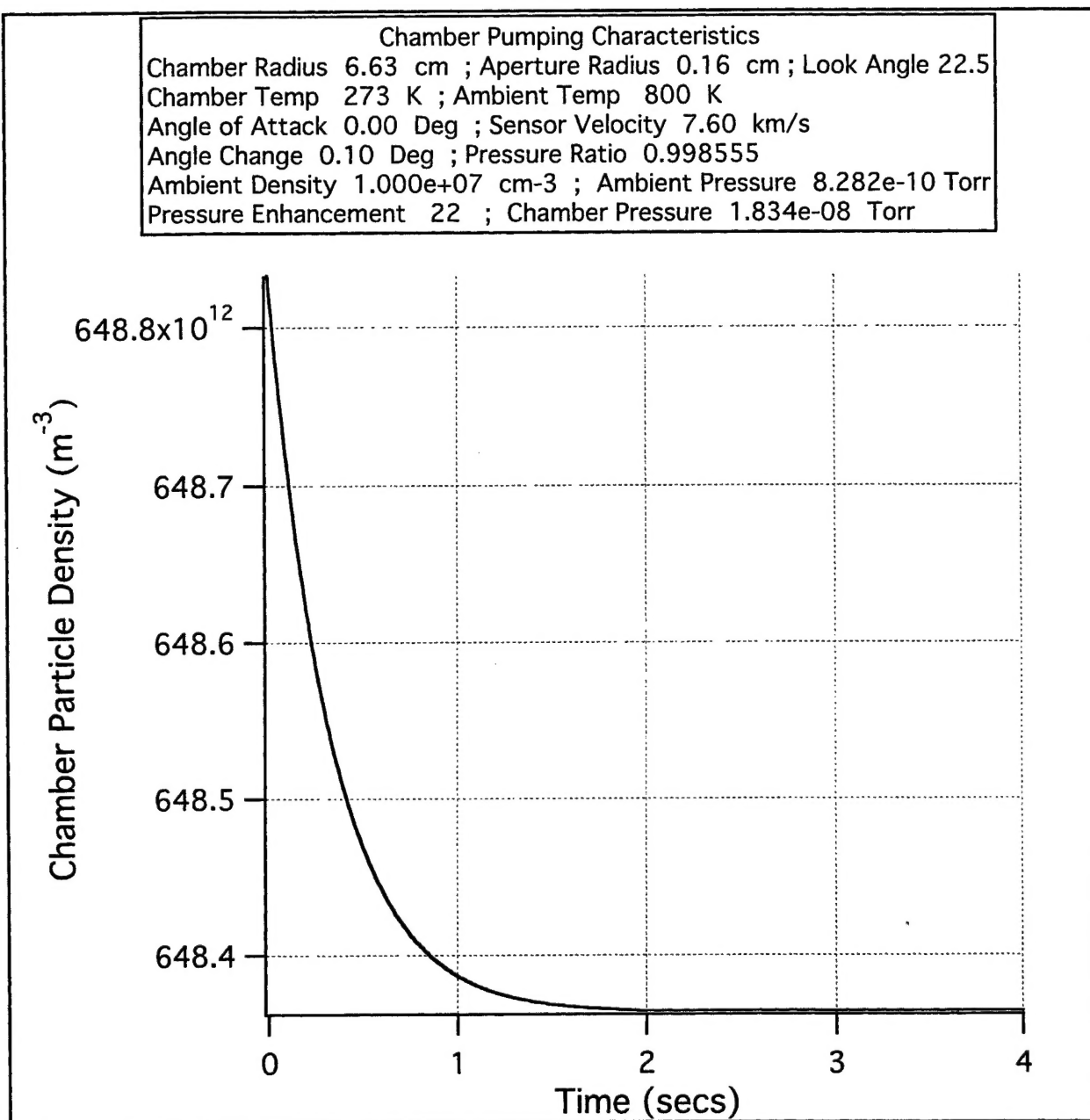


Figure 3. Computed Cross-Track Wind Sensor Performance.

Based on these expectations we designed and built the necessary hardware and electronics. Extensive testing of the instrument performance subsequently verified the expected performance and showed that we could build ionization gauges and associated electronics with the required sensitivity.

2.2 Ram Wind Sensor

The ram wind sensor derives the velocity along the ram direction by performing a retarding potential energy analysis on an ionized fraction of the flowing neutral gas. The incident ambient ions are electrostatically deflected from the instrument axis so that only the ions produced from the flowing neutral beam have access to the electron multiplier detector. A schematic illustration of the sensor configuration is shown in figure 4.

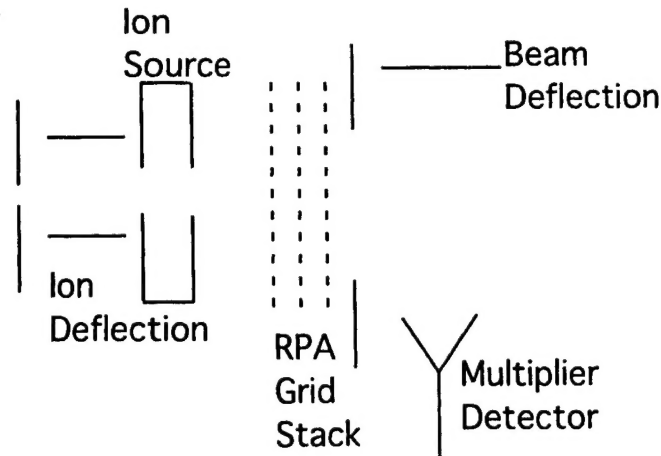


Figure 4. Schematic Illustration of Ram Wind Sensor Configuration.

Extensive laboratory testing of this configuration was made possible with support from this contract. In the laboratory it was necessary to add a bias grid to eject ions from the ion source since the spacecraft motion is not easily reproduced in a neutral beam. With this limitation we were able to show that the ion optics functions in an acceptable way and that the ion beam is completely collected even after substantial deviations produced when the retarding potential approaches the beam energy.

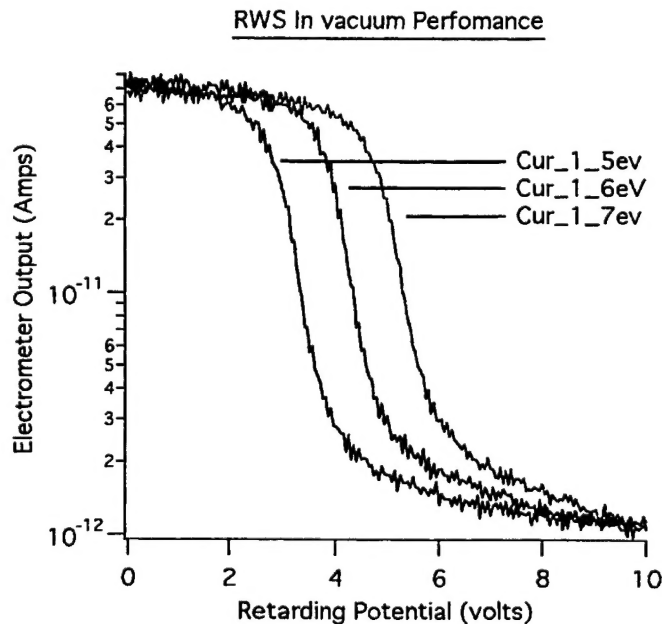


Figure 5. Ram Wind Sensor RPA Characteristics.

Figure 5 illustrates the laboratory outputs obtained when the draw-out potential was moved successively by one volt. This data provided the momentum to proceed toward the design of hardware and control electronics suitable for flight operations.

3. CONCLUSIONS

This research effort has resulted in the design and verification of a robust space instrument to measure the F-region neutral wind vector. The performance evaluation and verification work described here has been part of the overall effort to provide flight hardware and software for satellite borne instrumentation. The production of flight hardware and associated software development has been transitioned to a NASA supported effort but will also contribute substantially to the Air Force operational goals for forecasting radio scintillation. We now confidently look forward to obtaining essential measurements of the equatorial F-region neutral wind during the C/NOFS program.

